Biofeedback Assessment for Older People with Balance Impairment using a Low-cost Balance Board

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Abstract— **This paper studies the feasibility of using a low-cost game device called Wii Fit Balance Board® to measure the static balance of older people for diagnosing a balance impairment, which is caused by muscle weakness in stroke patients. Sixty participants were invited to attend the risk assessment that included a clinical test. Four biofeedback testing patterns were tested with the participants. Two machine learning algorithms were selected to experiment using 10-fold cross validation scenario. The results show that Artificial Neuron Network has the best evaluation performance of 86.67%, 80%, and 80% in three out of four biofeedback testing patterns. This demonstrates that the application of static balance measurement together with Wii Fit Balance Board® could be implemented as a tool to replace high-cost force plate systems.**

Keywords— static balance, Wii Fit Balance Board, classification, low-cost measuring tool, biofeedback

I. INTRODUCTION

The human ability to perform the routine activities of daily life requires the stable control of posture and balance [16]. The control of balance is the result of coordinated commands from the nervous system to maintain balance by integrating proprioceptive, vestibular, visual, motor control, and biomechanical information [20]. Stroke is a disease that can affect balance. Ischemic stroke is the most common form. This type of stroke is caused by narrowing of the arteries that supply blood to the brain resulting in ischemia. Haemorrhagic strokes are caused by arteries in the brain either leaking blood or bursting. Both types of stroke can result in brain damage. It is also the main cause of muscle weakness symptoms which is a major health concern for older people and results in higher rates of falls. Studies have revealed that most of the effects of stroke result in loss of or reduced motor control [11]. In 2010, approximately 10% of all deaths worldwide and about 4% of all disability-adjusted life expectancy was due to stroke [7].

In 2014, Thailand had a population about 64.6 million people, with 12.1 million children (18.7%) and 10 million older people aged over 65 years old (14.9%) [15]. Additionally, the survey in 2011 found that over half of the sampled population (53%) had reported symptoms that are, at least, the Non-Communicable Disease (NCD) problems. The most common symptoms were high blood pressure, high cholesterol, and diabetes, which are the main causes of stroke disease [6].

At the beginning of diagnosis and rehabilitation, the medical experts use clinical tests to measure muscle weakness in stroke patients by observing facial droop, arm drift, and speech [16]. With its evolution, physiotherapists have started to assess the ability to maintaining a line of activity in muscle weakness patients by using balance training, which is a tool to monitor stable posture control, together with balance weight from the force plate. In this balance training, the physiotherapist has to consider a static balance measurement. The equipment should provide a high stability in static balance measurement and generate good biomechanical result [1].

Similarly, to diagnose the levels of muscle weakness from stroke patient ability, static balance assessment is the standard measurement tool for evaluating a risk of balance impairment. This kind of assessment mainly uses the force plate device to measure the Centre of Pressure (COP) in a human-based standing posture. By using the device, a clinician can calculate the mean point of COP and its path length to use together with clinical tools for analysing their balance. Unfortunately, there is no standard device to measure balance for Thai older people.

The cost of using high-end devices like force plates are very expensive (approximately 250,000 THB) [8]. As a result, only a few hospitals can provide such measurement tools. This means that most of the patient population, especially in rural areas, would not have the opportunity to receive appropriate diagnosis. We discovered that the game controller device known as the Nintendo Wii Fit Balance Board® can be a replacement for expensive force plates. Such a device uses pressure sensors to control motion in gaming. Its cost is very low when compared to the standard medical device.

Table 1. Comparison of sensor and price between force and Nintendo Wii Fit Balance Board

Device	GASP Force Plate	Nintendo Wii Fit Balance Board
No. of pressure sensors	2500	4
Price (THB)	250,000	5,000

Table 1 shows a comparison on basic specification of different pressure sensors and prices between GASP force plate system for balance testing and Nintendo Wii Fit Balance Board®. The difference in cost between the GASP force plate and the Nintendo Wii Fit Balance Board® is mainly due to the difference in the number of sensors. With the Nintendo Wii Fit Balance Board®, it becomes possible to develop a tool for low–cost static balance measurement for stroke analysis in hospitals in the rural area.

This paper aims to improve the efficiency of the static balance assessment by proposing an affordable game controller device as the measuring tool with a decision support system paradigm. We invited sixty participants for clinical tests. We employed for biofeedback testing patterns and two machine learning algorithms in the experiment. Experimental results showed that Nintendo Wii Fit Balance Board®, with a suitable software system, can be used as a replacement for high-end pressure plates.

II. THEORETICAL BACKGROUND

A. Stroke Disease

Stroke is a serious condition in which poor blood flow to the brain results in cell death. Furthermore, clogged arteries or aneurysm rupture can result in brain damage that leads to muscle weakness symptoms. Stroke can be separated into two categories; 1) Ischemic stroke, and 2) Intracranial haemorrhage [7].

Ischemic stroke is caused by a blood clot forming in the artery leading to the brain or in one of the small vessels deep inside the brain. This type of stroke can result in a lack of sensation and reduction in cerebral hemisphere to control the muscle.

In Intracranial haemorrhage blood vessels made fragile by high blood pressure or amyloid angiopathy make the area vulnerable to rupture that can cause paralysis or risk of death. Especially in stroke patients, these symptoms always occur together with the brain defects. There are various symptoms which depend on the severity and location of the brain damage. For example; numbness or weakness of the face or limbs, paralysis of half of the body, a reduced ability to stand stably and decreases in posture that results in balance impairment.

B. Balance Assessment

Balance training is one postural assessment for patients which measures the abilities to identify balance impairment. This identification depends on the efficient processing of information which is encoded by several human sensory modalities [10].

Postural control (Balance) is the human mechanism to maintain balance, or the ability to maintain the centre of mass which is relative to the base body weight. In other words, postural control is the term used to describe the dynamics of the body to prevent balance impairment [21]. As the basis of human movement, an adaptation of their body to maintain the balance into the position is a body task. It requires many diverse components to work together to acquire sensory information, which is then evaluated by the central nervous system which in turn sends out the commands to perform the functions of the muscular skeletal system [4]. With this natural mechanism of the body, physiotherapists have adapted static balance training to assess the falling risk in human body [9].

Static balance training is a clinical tool used to measure the pressure exerted by a human standing on the force plate that can determine the effect of the Centre of Pressure (COP) [13]. This training scheme can assess the different results between standing with open eyes (OE) and standing with closed eyes (CE) to analyse a changing of the COP's sway from their pressure. Then, these results from static balance assessment are analysed to be the significant factors to balance impairment. The factors are sway path, sway area, velocity of sway and statistic assessment (e.g. summarized results, average, mean, significant.) Most static balance assessments do not focus on how to identify the fall risk or non-fall risk regarding personal health. However, there is research that applied the balance testing with an action in a game [1]. These game playing tests are used to analyse gestures in sports movement e.g. golf swing [10]. Balance testing is also used as a 'human sleepiness tester' to detect impairment of posture in steadiness due to staying awake for 24 hours [2].

Therefore, this paper come up with the idea of using the low-cost pressure sensors built-in the game controller device to measure balance ability in older people. The game controller called "Wii Fit Balance Board®" will be used to replace the force plate as an affordable measurement device for diagnosing the balance and predicting the risk of falling from the data of this static balance measurement.

C. Decision Support System (DSS)

Decision Support Systems have been used as the Information System in many fields and many organizations to manage their business, clinic, education, factory, etc., for a long time. Typically, the information system is categorised to be one of traditional data exploration because the database relationships are too complex or having too much data, which requires effective techniques to improve performance.

In clinical data, DSS is used for supporting diagnosis in many problems or diseases such as considering an image of operated brain surgery [19]. DSS is more widely used in the field of nursing, e.g. adoption of the system in Singapore [17]. DSS is also used to design the treatment course for patients in hospitals [3].

A classification technique is one of the famous machine learning approaches used to develop the DSS. It is an algorithm that learns a training set, containing a set of attributes and the respective outcome, usually called goal or prediction attribute.

There are several DSS that apply the concept of classification to their development with various types of algorithm. In the previous study, artificial neural networks evaluated its prediction performance or accuracy by comparing with three other classification techniques; Decision tree, Naïve Bayesian classifier and K-nearest neighbour, in predicting the pattern of static balance assessment for older people. The result showed that ANN was a suitable algorithm with the performance of 93% accuracy in a classification task [14].

Therefore, this paper continues to apply classification methods to predict a difference between normal and abnormal static balance in stroke patients. The two best classifiers to date are used in this study; artificial neural networks and support vector machine.

Artificial Neural Networks (ANNs)

ANNs are one in a family of prediction learning models which simulate biological neural networks. It is used to assess nearby functions that depend on many inputs or unknown assessment. ANNs are generally presented as an interconnection of neural nodes which exchange messages between levels. In computing, these connections can have many numeric weights that can be tuned based on experience, which is a kind of neural network that is adaptive to inputs and competent of learning.

M. Z. Uddin, [12], presented the multilayer perceptron technique as a kind of artificial neural network. The technique is extremely popular and widely documented as an architecture for a new human posture recognition method using principal configuration analysis. Furthermore, the ANNs become a good classification method for prediction purposes. It can approximate almost any regularity between its input and output. The ANNs can also be predicted and adjusted by a supervised training procedure called back propagation. Back propagation is a kind of gradient series method that finds an acceptable local minimum in the neural network weight space for achieving a minimal error. With the exception of the input layer, all layers compute their output with a weighted output formula, including an optional bias, and an activation function.

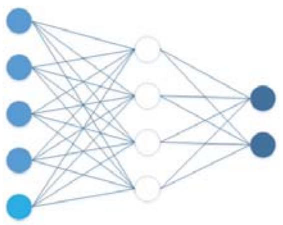

Figure 1. Artificial neural networks with single hiding layer

Support Vector Machine (SVM)

SVM is a powerful classifier that uses the strategy to separate a hyperplane. In practice, by giving a labelled training dataset, SVM as a supervised machine learning algorithm can output an optimal hyperplane which categorises new sets of data. The main process of SVM algorithms is to find the hyperplane that gives the shortest distance to the training dataset. This distance is a margin within data space. Therefore, the optimal hyperplane will maximise the margin of this training data. There are many methods to find the optimal hyperplane which is called as the kernel functions of SVM; linear, polynomial, radial basis function, sigmoid, etc. In this study, the linear kernel will be used to separate the data into two classes of normal and abnormal balance impairment.

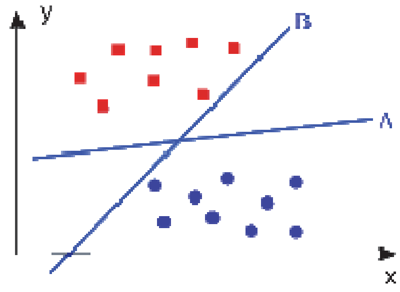

Figure 2. Support Vector Machine in linear vector

Therefore, these two algorithms will experiment with the measured data from low-cost game controller device including clinical data collected by using the balance assessment score from the medical experts.

D. *Existing Measurement Technology*

To measure balance and the ability to stand in humans, there is research testing balance by asking participants to play a game on the device called the Flat [10]. Therefore, balancing of human body while playing a game makes it possible to diagnose chronic stroke.

Many researches commonly use the Berg balance scale, the clinical tool, to test the risk of falling in chiropractic patients (neck pain and back pain). By applying this analysis with descriptive statistics, the calculation for each of the fall risk factors, and statistical tests were performed to compare quality of life by summarising the scores between those who were prone to falling and those who were not at a risk of falling [11]. However, there is no research presenting the use of a game controller device for diagnosing the static balance in the older population. Therefore, this study will focus on the analysis of static balance using the low–cost measuring equipment.

III. Proposed Method

To measure the stability in balance, a new low-cost framework is emphasized. This framework is purposed as a new measuring tool for static balance measurement in Stroke patients.

A. *Proposed Framework*

To measure the stability in muscle weakness from stroke patients, a new low-cost static balance measuring tool will be developed. In this study, four experimental scenarios are performed during measurement to analyse the balance impairment in the participants.

Closed-Eyes and Open-Eyes Biofeedback

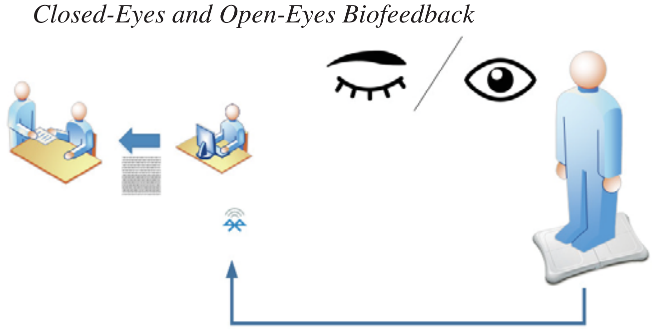

Figure 3. Closing- eyes and opening-eyes biofeedback

At the beginning of the static balance assessment, participants will be asked to test by standing still on Nintendo

Wii Fit Balance Board® together with closed and open eyes condition, figure 3. This protocol is a standard balance test before doing another biofeedback testing. The static balance value will be collected for clinical statistics and will be used as an input to the classification process later on.

Dual-Task Biofeedback

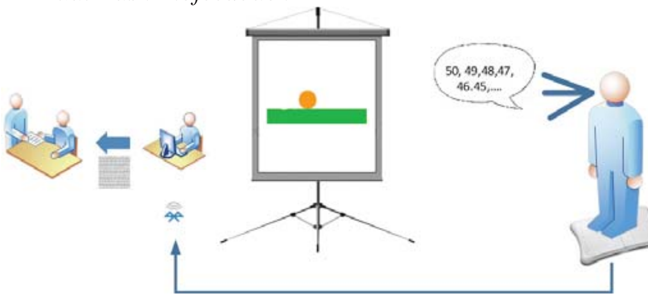

Figure 4. Dual-task biofeedback

From figure 4, the static balance training will be used to test the participants using Nintendo Wii Fit Balance Board® together with dual-tasks biofeedback by asking the patients to countdown numbers; decreasing by one started from fifty, and, at the same time, look at a rolling ball and balance it on a monitor screen during data collection. Then, data will be prepared and fed as an input for the classification process. After that, these identifying balance abilities, or prediction output, will be executed to compare with the data from traditional static balance clinical tests.

Single-Task Biofeedback

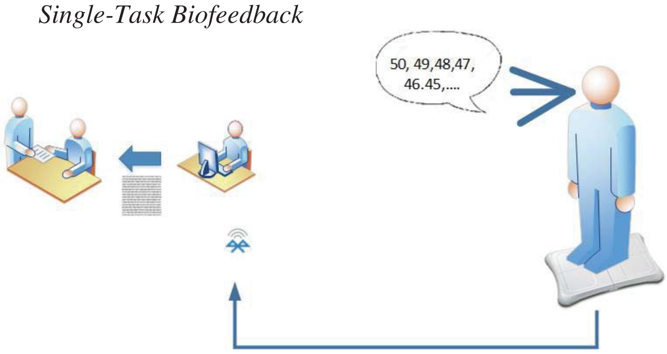

Figure 5. Single-task biofeedback

In this test, the static balance training will be used to assess the participants using Nintendo Wii fit Balance Board® together with single-task biofeedback by asking the patient to countdown a number decreasing by one started from fifty during data collection. Then, data will be prepared and fed as the input for the classification process.

Non-Task Biofeedback

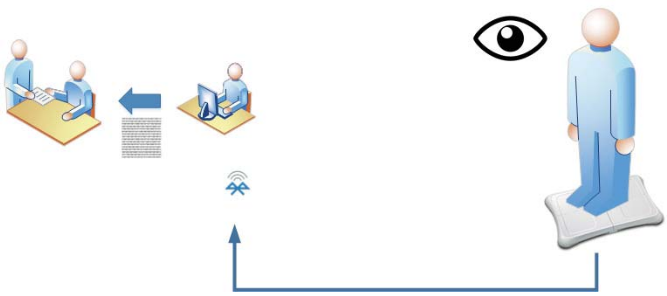

Figure 6. Non-task biofeedback

The patient stands with normal posture on the Nintendo Wii Fit Balance Board® and opens their eyes during the balance training in order to measure the participants with non-task biofeedback scheme in order to collect data. Then, the prepared data will be fed to the classification algorithm.

B. Data Collection

In this study, the participants were invited to perform their ability and attend these following steps:

Step 1: Collecting patient profile history using interview and diagnostic results from the physiotherapy experts.

Step 2: Collecting personal information (name, age, weight, height, and congenital disease) and more activity of daily life (ADLs) by using questionnaire.

Step 3: First clinical testing using five-time sit-to-stand test for evaluating balance impairment and collecting the data.

Step 4: Second clinical testing using time-up-and-go and ten-meter walk test for collecting the data.

Step 5: Training and testing in static balance by evaluating factors of static balance from a stand test, closing and opening eyes condition, and three biofeedback tasks; dual-task biofeedback, single-task biofeedback, and none-task biofeedback, using Nintendo Wii Fit Balance Board®. Each biofeedback task was performed within 30 seconds and repeated for three times of measurement.

Step 6: Calculating identified factors, Centre of Pressure (COP), from the static balance measurement using MFU Static Balance Test program [22] to assess the sway path, sway area, and velocity.

IV. EXPERIMENTAL RESULTS

Sixty stroke patients, aged over fifty-five years of age, were invited to participate in the research. These participants are villagers in the rural area of Phaya Mengrai district and Wiang Chai district, Chiang Rai province, Thailand. The participants were asked to provide general information about their activities of daily life (ADLs) using the structured questionnaire, sit-to-stand test and time-up-and-go, and ten-meter walk test, which were provided by the physiotherapist.

Then, the participants were asked to demonstrate their ability to maintain the line of gravity by standing still on the Nintendo Wii Fit Balance Board® with four proposed biofeedback conditions, shown in figures, 7, 8, and 9. The data collection was processed during this step by accessing the 2D coordination (x,y) of the COP via the sensor built into the Nintendo Wii Fit Balance Board®.

Figure 7. Static balance assessment on Nintendo Wii Fit Balance Board® using closed–eyes and open-eyes testing and non-task biofeedback testing

Figure 8. Static balance assessment on Nintendo Wii Fit Balance Board® with dual-task biofeedback testing

Figure 9. Static balance assessment on Nintendo Wii Fit Balance Board® with single-task biofeedback testing

This collected data was used to feed as the input for verifying the appropriate machine learning algorithm to predict balance impairment or non-balance impairment in stroke patients who have muscle weakness. In this study, the Rapid Miner [18] was used to test the data for evaluating the performance of the algorithms. A 10-fold cross-validation technique was used to evaluate the algorithms.

Table 2. Example of input data; (a) first 11 factors

Dataset	Age	Weight	Height	Gentle	ischemic	Intracranial	weakness	Impair	Path length	Velocity	Length Area
1	68	77	175	Male	Yes	Yes	Yes	Yes	293.77	9.79	68.56
2	58	44	152	Female	No	Yes	Yes	Yes	277.77	8.93	53.33
3	60	69	170	Male	Yes	No	Yes	No	75.05	2.5	34.65

Table 2. Example of input data and list of factors; (b) second 11 factors

Dataset	5 Times sit to	Time up and go	10 Meters Walk Test	10 Meters Walk Test	Walk 200 meters	Waking stick	Personal help	Bar assist	Fall in month	Fall in six month	Fall in twelve
1	Not pass	Pass	Pass	Pass	Yes	No	Yes	No	No	No	Yes
2	Not Pass	Not Pass	Pass	Pass	No	Yes	Yes	Yes	No	Yes	No
3	Pass	Pass	Pass	Pass	Yes	No	No	No	No	No	No

Table 2 shows an example of input vectors from collected data used to predict impairment and non-impairment in balance of stroke patients.

The experimental results of ANNs and SVM algorithms in table 3 and table 4, respectively, show that the best performance of both algorithms is the accuracy over 80% of correctness in ANNs. Although the ANNs performs the worst at single-task biofeedback with an accuracy of 66.7%, it still performs the best at 86.67% of accuracy with the standard static balance testing, the closing and opening eyes, when comparing with SVM in Figure 10.

Table 3. The accuracy of Static Balance Assessment in Neuron Network.

Testing	No. of Validation	Correct	Incorrect	Accuracy
Closing–opening eyes	15	12	3	80.00%
Dual-task Biofeedback	15	11	4	73.33%
Single-task Biofeedback	15	12	3	80.00%
None-task Biofeedback	15	11	4	73.33%

Table 4. The accuracy of Static Balance Assessment in Support Vector Machine.

Testing	No. of Validation	Correct	Incorrect	Accuracy
Closing–opening eyes	15	13	2	86.67%
Dual-task Biofeedback	15	12	3	80.00%
Single-task Biofeedback	15	10	5	66.67%
None-task Biofeedback	15	12	3	80.00%

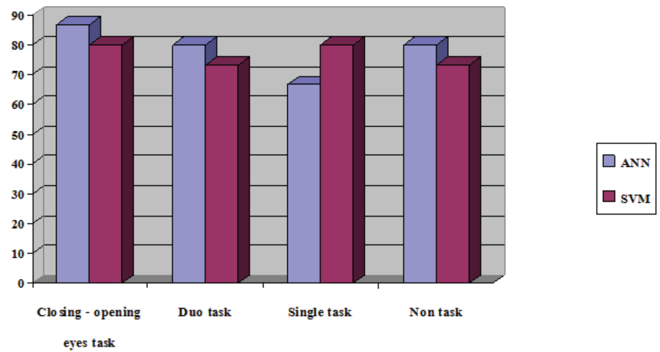

Figure 10. Algorithms comparison

Therefore, the ANNs is the more appropriate algorithm to classify balance impairment and non-balance impairment in older people who have stroke problems that could affect their risk of falling in the future. Hence, a development of the low–cost measuring tool and the system should be conducted.

V. CONCLUSION

With suffering on the stroke disease, the older people will be reduced their ability to control the posture and balance that can become more serious problem on falling. To prevent this problem, the medical governor tries to prevent the accidents that lead to a muscle weakness in stroke patients by providing a clinical measurement for evaluating their balance with the high-ends tools. Unfortunately, these tools are very expensive and cost a lot of resources in order to measure the difference in path length, velocity and sway area. Consequently, these devices are impossible to be achieved by the older people who live in the rural area.

Therefore, this paper proposed the new framework of using low-cost game controller device to measure the static balance, balance ability and then provide the decision making of balance impairment or non-balance impairment to the physiotherapist.

Two classification algorithms, Back Propagation Neuron Network, and Support Vector Machine were selected and tested for finding an appropriate predictor for dual-task biofeedback, single-task biofeedback, non-task biofeedback and closing-opening eyes task. A 10-fold cross validation was used to evaluate the algorithms. The experimental result shows that ANNs performs better with dual-task biofeedback, non-task biofeedback, and closing-opening eyes task. However, SVM can perform better in single-task biofeedback. Therefore, ANNs could be implemented as the static balance measurement system.

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